



Year: 2012

Right heart assessment by echocardiography: gender and body size matters

D'Oronzio, Umberto ; Senn, Oliver ; Biaggi, Patric ; Gruner, Christiane ; Jenni, Rolf ; Tanner, Felix C ; Greutmann, Matthias

Abstract: **BACKGROUND:** Published reference values for echocardiographic measurements of right-heart dimensions and function do not stratify for gender and body size. The aim of this study was therefore to assess the impact of gender and biometric characteristics on right-heart dimensions and function. **METHODS:** From the echocardiography database at a tertiary care center, 1,625 subjects (mean age, 44 ± 14 years; 47% men) with normal echocardiographic findings between 2000 and 2009 were identified. Gender differences and association with body surface area were assessed retrospectively for right atrial long-axis and short-axis dimensions, right ventricular short-axis dimension, end-diastolic and end-systolic right ventricular area, right ventricular fractional area change, and tricuspid annular plane systolic excursion. The impact of normal values stratified for gender and body surface area was tested in 24 patients with moderate-sized to large atrial septal defects. **RESULTS:** All dimensional right-heart measurements were significantly lower in women. Differences became smaller when measurements were indexed for body surface area, but significant differences persisted, particularly for right ventricular end-diastolic area (7.9 ± 1.6 vs 8.7 ± 1.8 cm²/m², $P < .001$) and right ventricular end-systolic area (4.0 ± 1.2 vs 4.7 ± 1.4 cm²/m², $P < .001$). Fractional area change and tricuspid annular plane systolic excursion indexed to body surface area were significantly higher in women ($50 \pm 7\%$ vs $46 \pm 9\%$ and 14 ± 3 vs 12 ± 2 mm/m², respectively, $P < .001$ for both comparisons). The use of upper reference ranges for end-diastolic right ventricular area stratified for gender and body surface area improved the detection of enlarged right ventricles in patients with moderate-sized to large atrial septal defects (92% vs 54%, $P < .007$). **CONCLUSIONS:** Gender and body surface area are important determinants of right ventricular dimensions and systolic function as measured on two-dimensional echocardiography. The investigators thus propose the use of measurements indexed to body surface area, with upper and lower reference ranges stratified for gender.

DOI: <https://doi.org/10.1016/j.echo.2012.08.013>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-73574>

Journal Article

Accepted Version

Originally published at:

D'Oronzio, Umberto; Senn, Oliver; Biaggi, Patric; Gruner, Christiane; Jenni, Rolf; Tanner, Felix C; Greutmann, Matthias (2012). Right heart assessment by echocardiography: gender and body size matters. *Journal of the American Society of Echocardiography*, 25(12):1251-8.

DOI: <https://doi.org/10.1016/j.echo.2012.08.013>

Right Heart Assessment by Echocardiography: Gender and Body Size Matters

Short title: Normal values of right heart

Umberto D'Oronzio¹, Oliver Senn², MD, Patric Biaggi¹, MD, Christiane Gruner¹, MD¹, Rolf Jenni¹, MD, Felix C. Tanner¹, MD, Matthias Greutmann¹, MD

Institutions:

- 1) Division of Cardiology, University Hospital of Zurich, Switzerland,
- 2) Institute of General Practice and Health Services Research, University of Zurich, Switzerland

Conflicts of interest: None

Relationship to industry: None

Corresponding author

Matthias Greutmann, MD, University Hospital of Zurich, Raemistrasse 100, 8091 Zurich, Switzerland. Tel.: ++41 44 255 3883, Fax: ++41 44 255 8701, Email: Matthias.Greutmann@usz.ch

Abstract

Background: Published reference values for echocardiographic measurements of right heart dimensions and function do not stratify for gender and body size. The aim of this study was therefore to assess the impact of gender and biometric characteristics on right heart dimensions and function.

Methods: From the echocardiography database at a tertiary care center 1625 subjects (mean age 44 ± 14 years, 47% males) with normal studies between 2000 and 2009 were identified. Gender differences and association with body surface area were assessed retrospectively for right atrial long- and short-axis dimensions, right ventricular short axis dimension, enddiastolic and endsystolic right ventricular area, right ventricular fractional area change (FAC) and tricuspid annular plane systolic excursion (TAPSE). **The impact of normal values stratified for gender and body surface area was tested in 24 patients with moderate-large atrial septal defects.**

Results: All dimensional right heart measurements were significantly lower in female subjects. Differences became smaller when measurements were indexed for body-surface area but significant differences persisted particularly for right ventricular enddiastolic area ($7.9 \pm 1.6 \text{ cm}^2/\text{m}^2$ versus $8.7 \pm 1.8 \text{ cm}^2/\text{m}^2$, $p < 0.001$) and right ventricular endsystolic area ($4.0 \pm 1.2 \text{ cm}^2/\text{m}^2$ versus $4.7 \pm 1.4 \text{ cm}^2/\text{m}^2$, $p < 0.001$). FAC and TAPSE indexed to body surface area were significantly higher in female subjects ($50 \pm 7\%$ versus $46 \pm 9\%$ and $14 \pm 3 \text{ mm}/\text{m}^2$ versus $12 \pm 2 \text{ mm}/\text{m}^2$ respectively, $p < 0.001$ for both comparisons). **The use of upper reference ranges for enddiastolic right ventricular area stratified for gender and body surface area improved the detection of enlarged right ventricles in patients with moderate-large atrial septal defects (92% versus 54%, $p < 0.007$).**

Conclusion: Gender and body surface area are important determinants of right ventricular dimensions and systolic function as measured on 2-dimensional echocardiography. We thus propose to use measurements indexed to body surface area, with upper and lower reference ranges stratified for gender.

Key words: Right ventricle; right ventricular function; echocardiography; gender; body surface area

Enlarged right ventricular dimensions are important clues for the diagnosis of some common forms of congenital heart lesions, such as atrial septal defects or partial anomalous pulmonary venous drainage and are among the major diagnostic criteria for arrhythmogenic right ventricular cardiomyopathy. (1-3) Recently published European guidelines for adults with congenital heart disease underscore the importance of right ventricular enlargement on echocardiography as the key factor for intervention in patients with atrial septal defects. (1)

Simple measures of echocardiographic right ventricular systolic function such as fractional area change (FAC) of the right ventricle and longitudinal shortening of the right ventricle have proven to bear important prognostic information in a variety of acquired cardiac lesions such as right heart failure in the setting of pulmonary hypertension or in patients with heart failure or coronary artery disease. (4-10)

Guidelines for the echocardiographic assessment of the right heart have recently been published. These guidelines provide a set of normal values for commonly used dimensional and functional right ventricular measurements. Normal values are derived from pooled data from different studies and do not stratify for gender, age and biometric data.(11)

The aim of this study was to determine the impact of age, gender and biometric data such as height, weight and body surface area on commonly used measures of right heart dimensions and function.

Methods

Study population

Patients were identified from the echocardiography database of a tertiary care center. In this database, for each patient the indication for the study, measured height, weight and a predefined set of echocardiographic measurements are recorded. For patients with a structurally and functionally normal heart the study is coded as 'normal' by a staff cardiologist. The criteria for classification of an echocardiographic study as 'normal' are: Sinus rhythm, absence of structural abnormalities, presence of none or minimal valvar regurgitation, no

evidence for pulmonary hypertension, normal systolic and diastolic function (except for the presence of an abnormal left ventricular relaxation pattern on myocardial inflow in patients older than 60 years) and the absence of pericardial effusion.

For the purpose of this study, all adult patients (≥ 18 years), with studies coded as 'normal' between 1st January 2000 and 31st December 2009 were identified from the echocardiographic database. The indications of all studies were reassessed and patients with preexisting conditions that might influence right heart dimensions or function were excluded. These exclusion criteria included disorders with potential lung affection (chronic obstructive lung disease, connective tissue disorders, history of pulmonary hypertension), disorders with potential affection of the myocardium (inherited myopathies, coronary artery disease) and disorders potentially leading to acute or chronic changes of hemodynamics (systemic infections, pregnancy, disorders typically associated with anemia or changes in cardiac output). Analysis of the data adheres to our institutional ethics board guidelines.

Echocardiographic measurements

All patients underwent standard transthoracic echocardiographic (TTE) examination with commercially available equipment. For the purpose of this study the following echocardiographic dimensional measurements were assessed retrospectively: Right ventricular enddiastolic midventricular short axis dimension on apical 4-chamber view, right ventricular enddiastolic and endsystolic area on apical 4-chamber view and endsystolic right atrial long- and short axis dimensions on apical 4-chamber view. Measures of right ventricular systolic function included right ventricular longitudinal shortening assessed by M-mode measurement of the lateral tricuspid valve annulus (Tricuspid annular plane systolic excursion; TAPSE in millimeters) and right ventricular fractional area change (FAC), calculated by the formula: $FAC = [(enddiastolic\ right\ ventricular\ area\ in\ cm^2 - endsystolic\ right\ ventricular\ area\ in\ cm^2) / enddiastolic\ right\ ventricular\ area\ in\ cm^2] * 100$. Measurements are illustrated in **Figure 1**. Height and weight were measured at the time of echocardiography and body surface area was calculated using the Mosteller formula. (12)

Impact of indexed reference values on detection of enlarged right ventricles in a group of adults with moderate to large sized atrial septal defects

To demonstrate the clinical impact of normalized versus non-normalized right heart measurements we analyzed a group of patients with moderate to large sized atrial septal defects. For this purpose we identified 24 patients who had interventional closure of a secundum type atrial septal defect with a large Amplatzer septal occluder ($\geq 20\text{mm}$). Within this patient group it was tested, whether upper reference ranges stratified for body surface area and gender would improve detection of enlarged right ventricles as compared to non-indexed reference ranges as proposed in the guidelines (enddiastolic right ventricular area on 4-chamber view $> 25 \text{ cm}^2$). (11)

Statistical analysis

Statistical analysis was performed using SPSS version 19.0 (SPSS, Inc., Chicago, IL). Descriptive data for continuous variables are presented as means \pm SD and dichotomous variables as percentages. Histograms were used to confirm normal distribution of continuous variables. For comparison between groups, Student's t-test was used. Pearson-correlation analysis was used to assess associations between right heart dimensional and functional measurements, age and biometric data. Lower and upper limits of normal were defined as mean ± 2 standard deviations. (11) A p-value of < 0.05 (two-sided) was considered to be significant.

Results

Study population

From a total of 46'367 echocardiograms in adult patients performed between 2000 and 2009, in 2743 (6%) the studies were coded as 'normal'. Of these subjects, 1118 were excluded from the current analysis because of potentially confounding preexisting disease. Reasons for exclusion were: Coronary artery disease in 168, lung disease in 97, connective

tissue disorders in 211, inherited myopathies in 16, infection with the human immune-deficiency-virus in 20 subjects, studies performed in patients in the intensive care unit in 201 cases, acute leukemia or lymphoma in 278 subjects, known anemia in 66 cases and 61 studies in women who were pregnant.

The remaining 1625 subjects (47% males, mean age 44 ± 14 years, range 18-92 years) were analyzed for the purpose of this study. Mean height was 171 ± 10 cm, mean weight was 72 ± 15 kg and mean body surface area was 1.84 ± 0.22 m². Indications for echocardiograms in these subjects are shown in **Table 1**. Not every measurement was available in every patient. **Table 2** illustrates the number of available measurement for each of the analyzed echocardiographic parameters ranging from 70% (right heart enddiastolic area) to 92% (right atrial long axis dimension), and the corresponding averages of age and biometric parameters for these groups.

Correlation of right heart measurements with age

There was no statistically significant correlation between age and right ventricular systolic function (FAC and TAPSE), right atrial short axis dimension, right ventricular short axis dimension and right ventricular systolic area ($r = -0.05 - 0.01$; $p > 0.1$ for all). There was a weak, although statistically significant, positive correlation between age and right atrial long axis dimension and a weak negative correlation between age and right ventricular enddiastolic area ($r = 0.09$ and -0.09 respectively, $p = 0.001$ and 0.004 respectively) (see **Figure 2**). These weak correlations are not of clinical importance.

Gender differences in right heart dimensions and function

Right atrial and right ventricular dimensions were all significantly larger in males, whereas FAC was significantly higher in women and no statistically significant difference was found for TAPSE. **Figure 3** illustrates gender differences for these measurements. The most striking differences were found for measurements of right ventricular enddiastolic and

endsystolic areas, where the absolute differences between means for genders were 3.4cm^2 and 2.3 cm^2 , respectively, which accounts for 25% and 34%, respectively, of absolute values.

Correlation between biometric data and right heart dimensions and systolic function

Male study subjects were on average significantly taller ($178 \pm 8\text{ cm}$ versus $165 \pm 7\text{cm}$, $p < 0.0001$) and heavier ($79 \pm 14\text{ kg}$ versus $66 \pm 13\text{kg}$, $p < 0.0001$) than their female counterparts and had corresponding higher body surface areas ($1.97 \pm 0.19\text{ m}^2$ versus $1.73 \pm 0.18\text{ m}^2$, $p < 0.0001$) and a higher body mass index ($25.2 \pm 4.6\text{ kg/m}^2$ versus $24.2 \pm 4.9\text{ kg/m}^2$, $p < 0.0001$).

A moderate correlation for all dimensional right heart measurements with all biometric characteristics was found, with the strongest correlations for body surface area (see **Table 3, Figure 4**). Correlation of TAPSE and FAC with biometric data was relatively weak (see **Table 3, Figure 4**).

To demonstrate the potential clinical significance of correlations of dimensional right heart measurements with biometric data, **Figure 5** demonstrates the differences for all dimensional right heart measurements between subjects in the lowest and the highest quartile of body surface areas.

Gender differences for right heart dimensions and function when normalized to body surface area

When right heart dimensions were normalized to body surface area, right atrial short axis and right ventricular short axis dimensions were no longer significantly different between genders. However, even when normalized for body surface area, a significant difference persisted for right atrial long axis dimensions and particularly for measurements of enddiastolic and endsystolic right ventricular areas on 4-chamber view (see **Table 4**).

Although the differences between genders become smaller when values are indexed for body surface area, average differences between genders were still 6-18%. Interestingly, indexed TAPSE became significantly higher in female subjects, which fits with the

observation that FAC, another parameter of systolic right ventricular function was significantly higher in female subjects.

Reference ranges for measurements of right ventricular dimensions and systolic function normalized to body surface area and stratified for gender

As suggested in published guidelines, reference ranges for upper and lower limits of normal are defined as mean values ± 2 standard deviations. (11) Based on the results of this study, **Table 5** summarizes mean values for right heart measurements indexed to body surface area with reference values stratified for gender.

Impact of indexed reference values on detection of enlarged right ventricles in a group of adults with moderate to large sized atrial septal defects

The group of 24 patients (38% males) with moderate to large atrial septal defects (mean age 46 ± 17 years) had an average body surface area of $1.8 \pm 0.1 \text{ m}^2$. Average right ventricular enddiastolic area not indexed to body surface area was $25.5 \pm 3.5 \text{ cm}^2$ and right ventricular enddiastolic area indexed to body surface area was $14.5 \pm 2.0 \text{ cm}^2/\text{m}^2$. When using non-indexed upper reference ranges for right ventricular enddiastolic area ($> 25\text{cm}^2$) 13/24 patient (54%) were identified as having enlarged right ventricles. (11) In contrast, when using upper reference ranges stratified for body surface area and gender, 22/24 patients (92%) would have been identified as having enlarged right ventricles ($p = 0.007$).

Discussion

Right heart dimensions and simple measurements of right ventricular systolic function such as FAC and TAPSE are commonly used for echocardiographic assessment of right heart dimensions and systolic function. Yet normal reference values for these measurements are based on results from numerous, at times small studies. The number of normal subjects used to define reference ranges for right ventricular dimensions and function range from 267

subjects for right atrial long-axis dimension (derived from 8 different studies) and a total of 2320 subjects for TAPSE (derived from 46 individual studies). (11) Current reference values are not stratified for gender and biometric data such as body surface area. (11)

The present study demonstrates that there are important gender differences for many of these echocardiographic measurements. These differences are mainly driven by different biometric characteristics between men and women. However, even after normalization of measurements for body surface area, statistically significant gender differences for right heart dimensions and systolic function persist. In agreement with the present findings, studies defining gender-specific normal values for the right heart using cardiovascular magnetic resonance imaging or 3-dimensional echocardiography have found similar results, with right ventricular volumes being significantly larger in men than women. The differences became smaller, but still persisted when normalized for body surface area. While some studies found no significant differences for right ventricular function between genders, others found higher right ventricular ejection fraction in women. (13-16)

In contrast to cardiac magnetic resonance imaging, only few studies evaluated the impact of gender and biometric measurements on right heart dimensions. Kjaergaard et al found significantly higher right ventricular volumes in men compared to women. These differences became smaller, when volumes were normalized for body surface area and disappeared when dimensions were normalized to lean body mass. (17) In a much larger study of young healthy adults, Ogunyankin, et al demonstrated very similar results for gender specific upper reference ranges of right ventricular enddiastolic areas as in the present study. (18) Data on the impact of ageing on right heart dimensions and function are more conflicting. Maceira et al. reported a significant decrease of right ventricular mass and volumes with ageing, as measured by cardiovascular magnetic resonance imaging but a significant increase of right ventricular ejection fraction. (14) In contrast, echocardiographic studies showed no significant changes of right ventricular dimensions with ageing, very similar to the results in the present study. (19, 20) While in some studies TAPSE slightly decreased with ageing, others did not find this correlation. (17, 19, 20) More recent studies using three-

dimensional echocardiography found a slight decrease of right ventricular volumes with ageing but no significant changes in right ventricular ejection fraction. (16) Within the present study ageing had no important impact on right heart dimensions or function.

Clinical implications

Two-dimensional echocardiography remains the main screening tool for anatomical and functional assessment of the right heart. Identification of a dilated right ventricle is important for diagnosis in patients with interatrial shunt lesions and patients with arrhythmogenic right ventricular cardiomyopathy. In patients with atrial septal defects dilated right ventricular chambers are the most important findings triggering intervention, even in asymptomatic patients and are preferred over calculation of shunt fraction. (1) To have reliable and robust data for normal values is therefore of clinical importance in these patients.

As illustrated in this study in a small group of patients with moderate to large sized atrial septal defects, the use of reference values stratified for body surface area and gender allowed more accurate identification of patients with enlarged right ventricles. Given these findings the use of gender specific normal values stratified for body surface area may impact clinical decision making.

In many cardiac diseases such as coronary artery disease, dilated cardiomyopathy or pulmonary hypertension, simple measures of right ventricular systolic function such as FAC or TAPSE have been identified as important prognostic markers. (4-10) Again, it might be of clinical importance to identify subjects with abnormal right ventricular function.

Limitations

Some of the differences between genders are relatively small when measurements are indexed to body surface area. Furthermore, the variance within measurements (technical variability, intra- and inter-observer variability) may exceed these differences in daily practice. Despite a predefined protocol for echocardiographic measurements at our institution, the

analysis of the data was retrospective. Given the retrospective nature of the analysis, intra- and inter-observer variability for the analyzed measurements has not been assessed. Indeed, only few studies have addressed intra- and inter-observer variability of conventional right heart measurements. In one study of patients with end-stage lung disease, intra- and interobserver variability for right ventricular dimensions was tested. Variability was defined as the average percentage difference of the 2 measurements. (21) Mean intra- and interobserver variability for right ventricular enddiastolic area was $2.9\% \pm 0.8\%$ and $3.6\% \pm 1.9\%$ and variability for right ventricular endsystolic area was $3.3 \pm 1.3\%$ and $4.1\% \pm 2.1\%$. Right ventricular short axis dimension showed a larger intra- and interobserver variability of $10.4\% \pm 11.7\%$ and $11.7\% \pm 10.7\%$. Another study using an echocardiographic model based on enddiastolic right ventricular enddiastolic area for estimation of right ventricular enddiastolic volumes in patients with repaired tetralogy of Fallot found comparable intra- and interobserver variability for echocardiography and magnetic resonance imaging. (22) To minimize variability a strict institutional protocol for image acquisition and conventions for measurement of right heart dimensions are important for the reproducibility of these measurements. Whether the observed differences of 6-18% between genders for these measurements may have a clinical impact needs to be determined in clinical outcome studies.

The study cohort did, for most, not consist of normal healthy subjects but of patients referred for echocardiography for clinical purposes. To address this potential limitation patients with potentially confounding underlying diseases were excluded.

Although most patients were Caucasians, there is no exact data on racial background and thus these results may not be generalizable to patient groups with other ethnicities. Other results indicate no difference between young blacks and whites, but a significant lower right ventricular dimensions of Chinese individuals compared to Caucasians, even after adjusting for body surface area. (18, 23)

Only subjects, whose echocardiograms were judged 'normal' by one of the staff cardiologists, were included. It may be that normal subjects with 'large' right atrial or right

ventricular chambers were judged 'abnormal' by some of these cardiologists and thus there may be a bias towards smaller normal values for right heart dimensions in this study.

Conclusion

Gender and body surface area are important determinants of right ventricular dimensions and systolic function as measured on 2-dimensional echocardiography. We thus propose to use measurements indexed to body surface area, with upper and lower reference ranges stratified for gender.

References

1. Baumgartner H, Bonhoeffer P, De Groot NM, de Haan F, Deanfield JE, Galie N, et al. ESC Guidelines for the management of grown-up congenital heart disease (new version 2010). *Eur Heart J*. 2010;31(23):2915-57.
2. Warnes CA, Williams RG, Bashore TM, Child JS, Connolly HM, Dearani JA, et al. ACC/AHA 2008 Guidelines for the Management of Adults with Congenital Heart Disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to develop guidelines on the management of adults with congenital heart disease). *Circulation*. 2008;118(23):e714-833.
3. Marcus FI, McKenna WJ, Sherrill D, Basso C, Bauce B, Bluemke DA, et al. Diagnosis of arrhythmogenic right ventricular cardiomyopathy/dysplasia: proposed modification of the task force criteria. *Circulation*. 2010;121(13):1533-41.
4. Ghio S, Recusani F, Klersy C, Sebastiani R, Laudisa ML, Campana C, et al. Prognostic usefulness of the tricuspid annular plane systolic excursion in patients with congestive heart failure secondary to idiopathic or ischemic dilated cardiomyopathy. *Am J Cardiol*. 2000;85(7):837-42.
5. Dini FL, Fontanive P, Panicucci E, Andreini D, Chella P, De Tommasi SM. Prognostic significance of tricuspid annular motion and plasma NT-proBNP in patients with heart failure and moderate-to-severe functional mitral regurgitation. *Eur J Heart Fail*. 2008;10(6):573-80.
6. Engstrom AE, Vis MM, Bouma BJ, van den Brink RB, Baan J, Jr., Claessen BE, et al. Right ventricular dysfunction is an independent predictor for mortality in ST-elevation myocardial infarction patients presenting with cardiogenic shock on admission. *Eur J Heart Fail*. 2010;12(3):276-82.
7. Ghio S, Klersy C, Magrini G, D'Armini AM, Scelsi L, Raineri C, et al. Prognostic relevance of the echocardiographic assessment of right ventricular function in

- patients with idiopathic pulmonary arterial hypertension. *Int J Cardiol.* 2010;140(3):272-8.
8. Forfia PR, Fisher MR, Mathai SC, Houston-Harris T, Hemnes AR, Borlaug BA, et al. Tricuspid annular displacement predicts survival in pulmonary hypertension. *Am J Respir Crit Care Med.* 2006;174(9):1034-41.
 9. Holley AB, Cheatham JG, Jackson JL, Moores LK, Villines TC. Novel quantitative echocardiographic parameters in acute PE. *J Thromb Thrombolysis.* 2009;28(4):506-12.
 10. Anavekar NS, Skali H, Bourgoun M, Ghali JK, Kober L, Maggioni AP, et al. Usefulness of right ventricular fractional area change to predict death, heart failure, and stroke following myocardial infarction (from the VALIANT ECHO Study). *Am J Cardiol.* 2008;101(5):607-12.
 11. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *J Am Soc Echocardiogr.* 2010;23(7):685-713; quiz 86-8.
 12. Mosteller RD. Simplified calculation of body-surface area. *N Engl J Med.* 1987;317(17):1098.
 13. Buechel EV, Kaiser T, Jackson C, Schmitz A, Kellenberger CJ. Normal right- and left ventricular volumes and myocardial mass in children measured by steady state free precession cardiovascular magnetic resonance. *J Cardiovasc Magn Reson.* 2009;11:19.
 14. Maceira AM, Prasad SK, Khan M, Pennell DJ. Reference right ventricular systolic and diastolic function normalized to age, gender and body surface area from steady-state free precession cardiovascular magnetic resonance. *Eur Heart J.* 2006;27(23):2879-88.

15. Alfakih K, Plein S, Thiele H, Jones T, Ridgway JP, Sivananthan MU. Normal human left and right ventricular dimensions for MRI as assessed by turbo gradient echo and steady-state free precession imaging sequences. *J Magn Reson Imaging*. 2003;17(3):323-9.
16. Tamborini G, Marsan NA, Gripari P, Maffessanti F, Brusoni D, Muratori M, et al. Reference values for right ventricular volumes and ejection fraction with real-time three-dimensional echocardiography: evaluation in a large series of normal subjects. *J Am Soc Echocardiogr*. 2010;23(2):109-15.
17. Kjaergaard J, Sogaard P, Hassager C. Quantitative echocardiographic analysis of the right ventricle in healthy individuals. *J Am Soc Echocardiogr*. 2006;19(11):1365-72.
18. Ogunyankin KO, Liu K, Lloyd-Jones DM, Colangelo LA, Gardin JM. Reference values of right ventricular end-diastolic area defined by ethnicity and gender in a young adult population: the CARDIA study. *Echocardiography*. 2011;28(2):142-9.
19. Chiha J, Boyd A, Thomas L. Does normal ageing alter right ventricular relaxation properties? A tissue Doppler study. *Heart Lung Circ*. 2010;19(7):406-12.
20. Innelli P, Esposito R, Olibet M, Nistri S, Galderisi M. The impact of ageing on right ventricular longitudinal function in healthy subjects: a pulsed tissue Doppler study. *Eur J Echocardiogr*. 2009;10(4):491-8.
21. Schenk P, Globits S, Koller J, Brunner C, Artemiou O, Klepetko W, et al. Accuracy of echocardiographic right ventricular parameters in patients with different end-stage lung diseases prior to lung transplantation. *J Heart Lung Transplant*. 2000;19(2):145-54.
22. Greutmann M, Tobler D, Biaggi P, Mah ML, Crean A, Oechslin EN, et al. Echocardiography for assessment of right ventricular volumes revisited: a cardiac magnetic resonance comparison study in adults with repaired tetralogy of Fallot. *J Am Soc Echocardiogr*. 2010;23(9):905-11.

23. Tandri H, Daya SK, Nasir K, Bomma C, Lima JA, Calkins H, et al. Normal reference values for the adult right ventricle by magnetic resonance imaging. *Am J Cardiol.* 2006;98(12):1660-4.

Figure legends

Figure 1: Measurements of right heart dimensions and systolic function. Panel A: 4-chamber view at end-diastole (arrow) showing measurement of right ventricular enddiastolic area and right ventricular short axis (double headed arrow). Panel B: 4-chamber view at end-systole (arrow) demonstrating measurements of right ventricular systolic area, right atrial long- and short-axis dimensions (double headed arrows). Panel C: M-Mode recording through the lateral tricuspid annulus on apical 4-chamber view, demonstrating measurement of tricuspid annular plane systolic excursion (double headed arrow).

Figure 2: Scatter plots illustrating the weak correlation between age and right ventricular enddiastolic area and between age and right atrial long-axis dimension (dashed lines represent 95% confidence intervals of the Pearson correlation coefficients)

Figure 3: Comparison of right atrial and right ventricular dimensions and measures of right ventricular systolic function between genders

Figure 4: Scatter plots illustrating the correlations between right heart dimension and body surface area (dashed lines represent 95% confidence intervals of the Pearson correlation coefficients)

Figure 5: Comparison for dimensional right heart measurements between subjects in the lowest and highest quartile of body surface area

Table legends

Table 1: Indications for echocardiograms of all 1625 included subjects

Table 2: Number of subjects in whom individual measurements were available with corresponding biometric data for each group

Table 3: Correlations between echocardiographic right heart measurements and biometric parameters

Table 4: Gender differences when echocardiographic measurements are indexed to body surface area

Table 5: Reference values for right heart measurement with and without stratifying for gender and for body surface area

[Click here to download high resolution image](#)

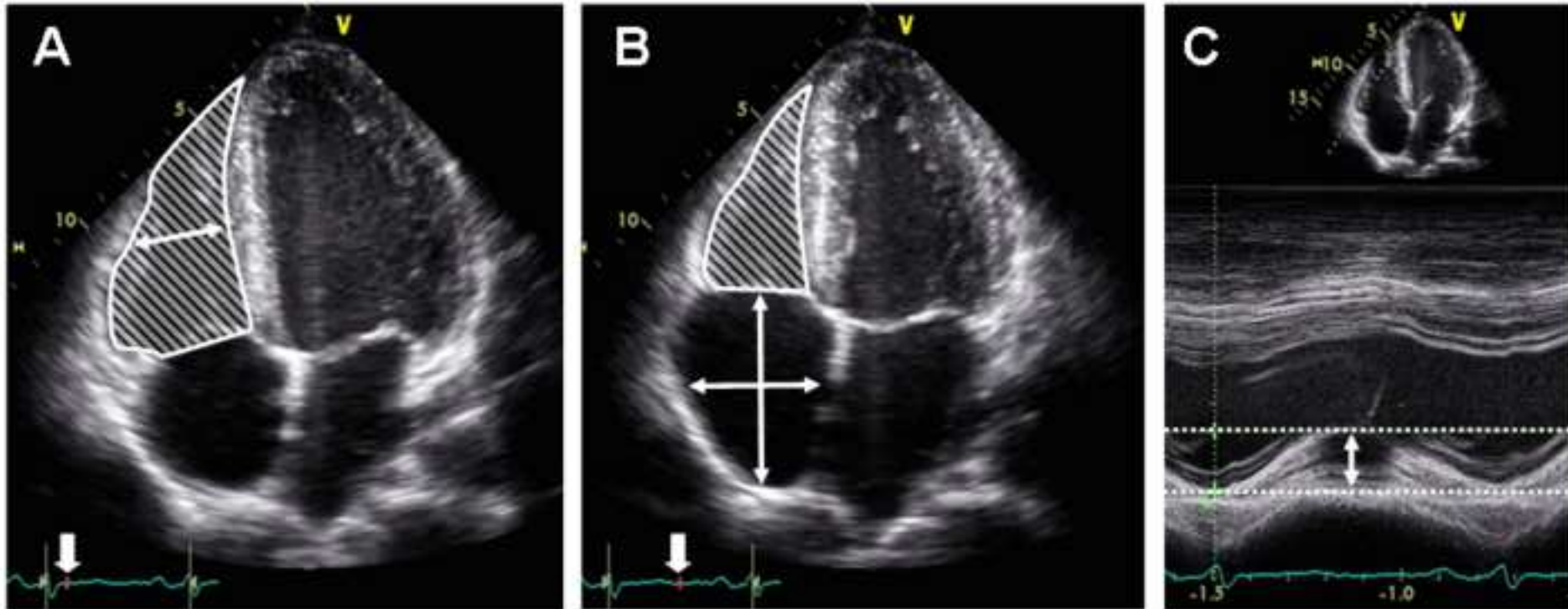


Figure 2
[Click here to download high resolution image](#)

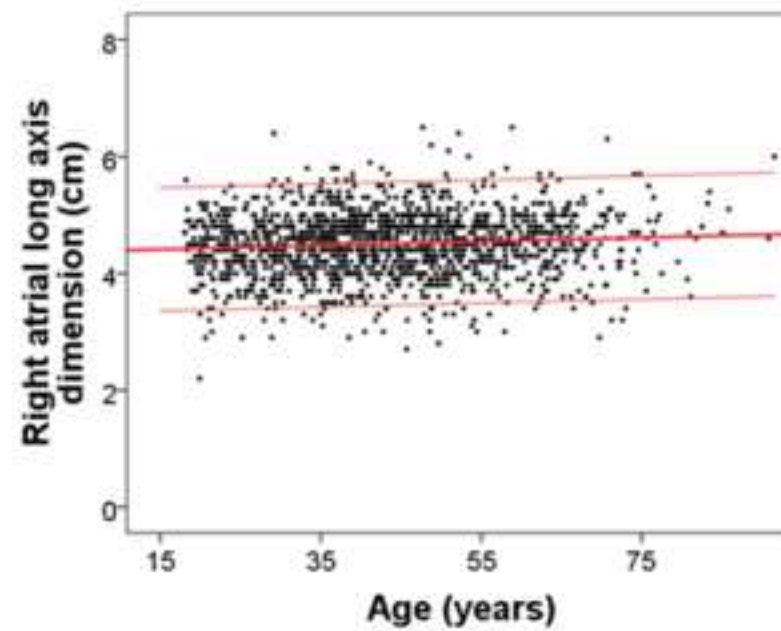
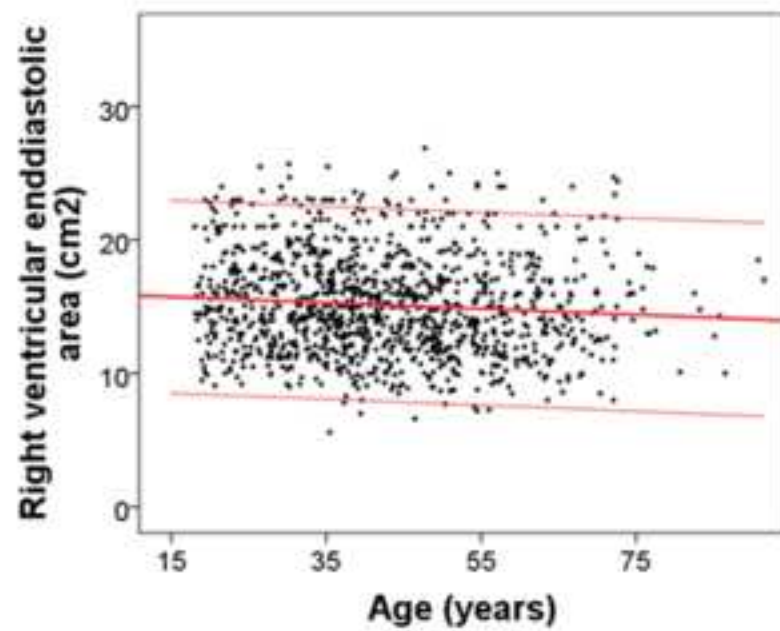
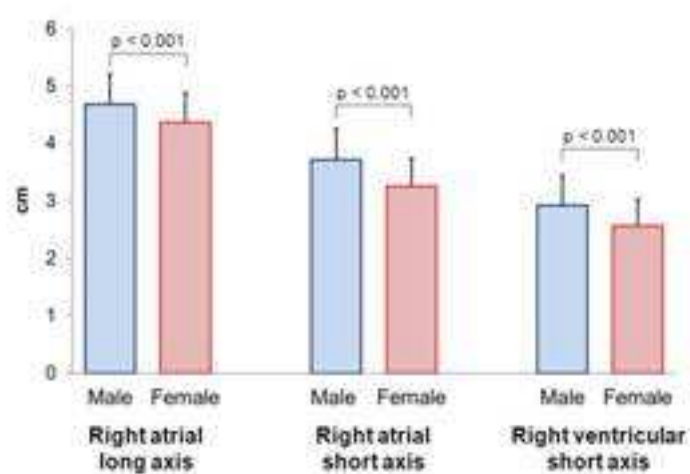
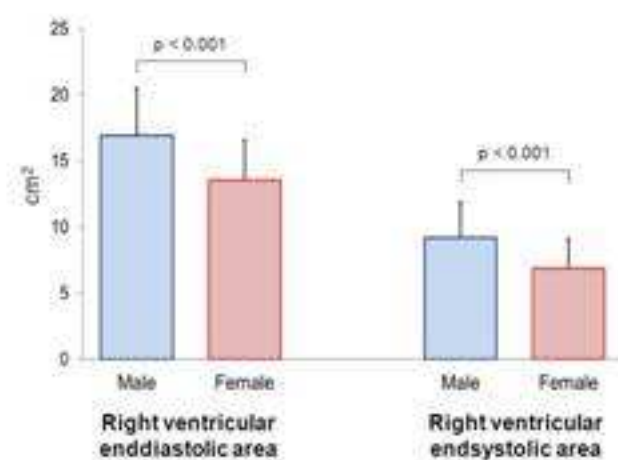


Figure 3
[Click here to download high resolution image](#)

A: Right atrial and ventricular linear dimensions



B: Right ventricular diastolic and systolic areas



C: Right ventricular systolic function

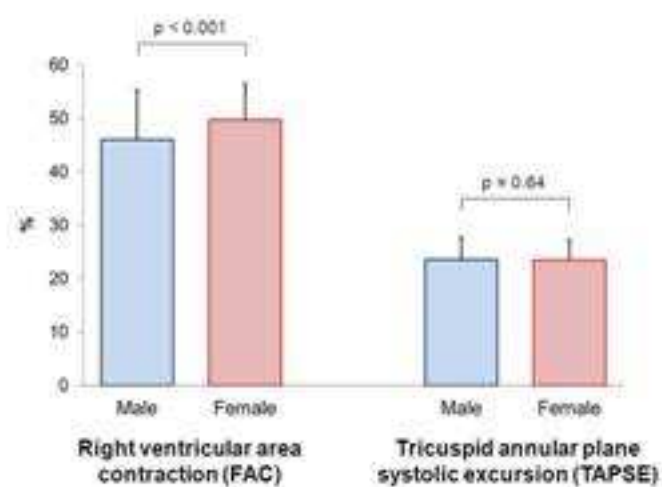


Figure 4
[Click here to download high resolution image](#)

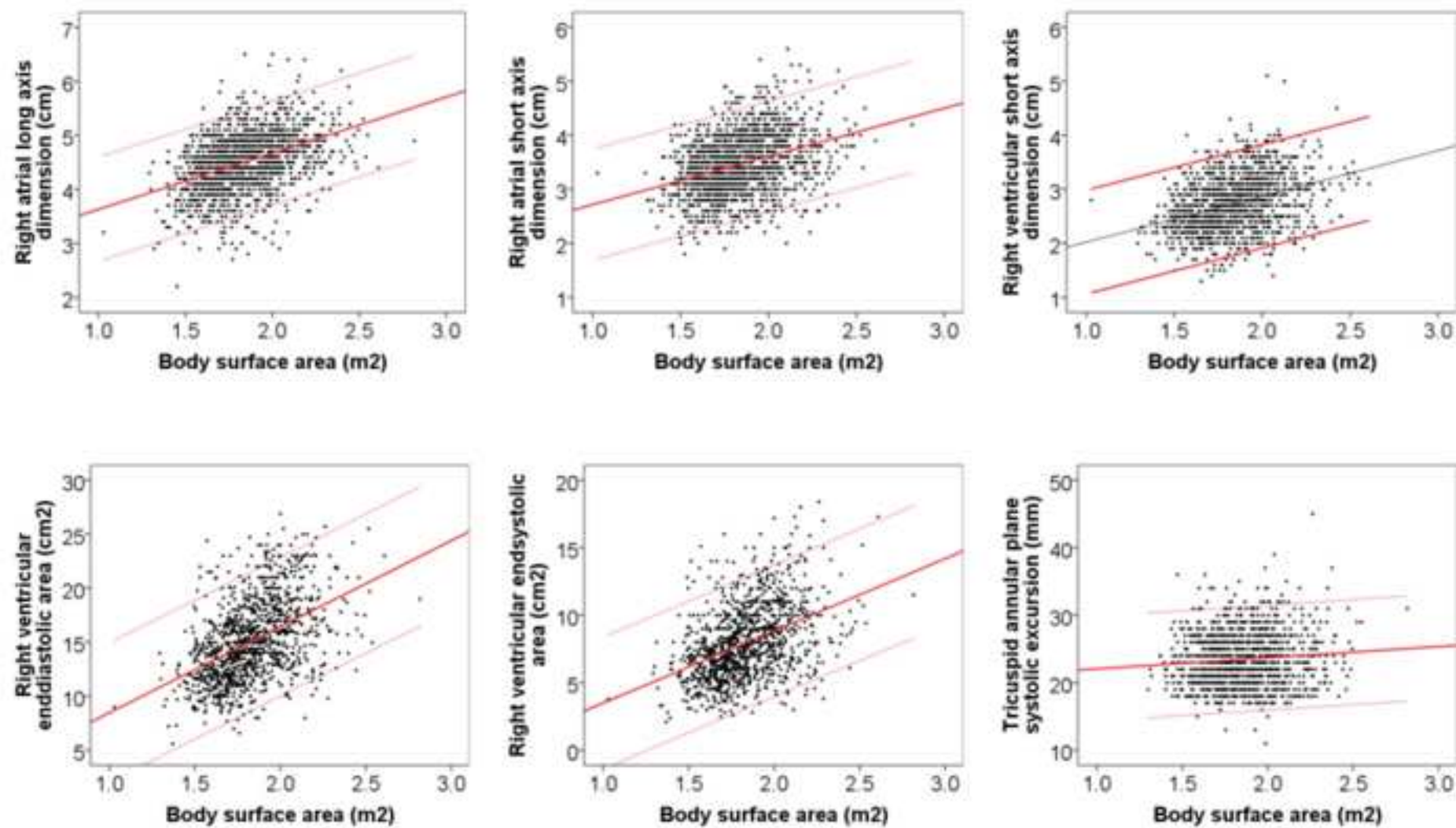


Figure 5
[Click here to download high resolution image](#)

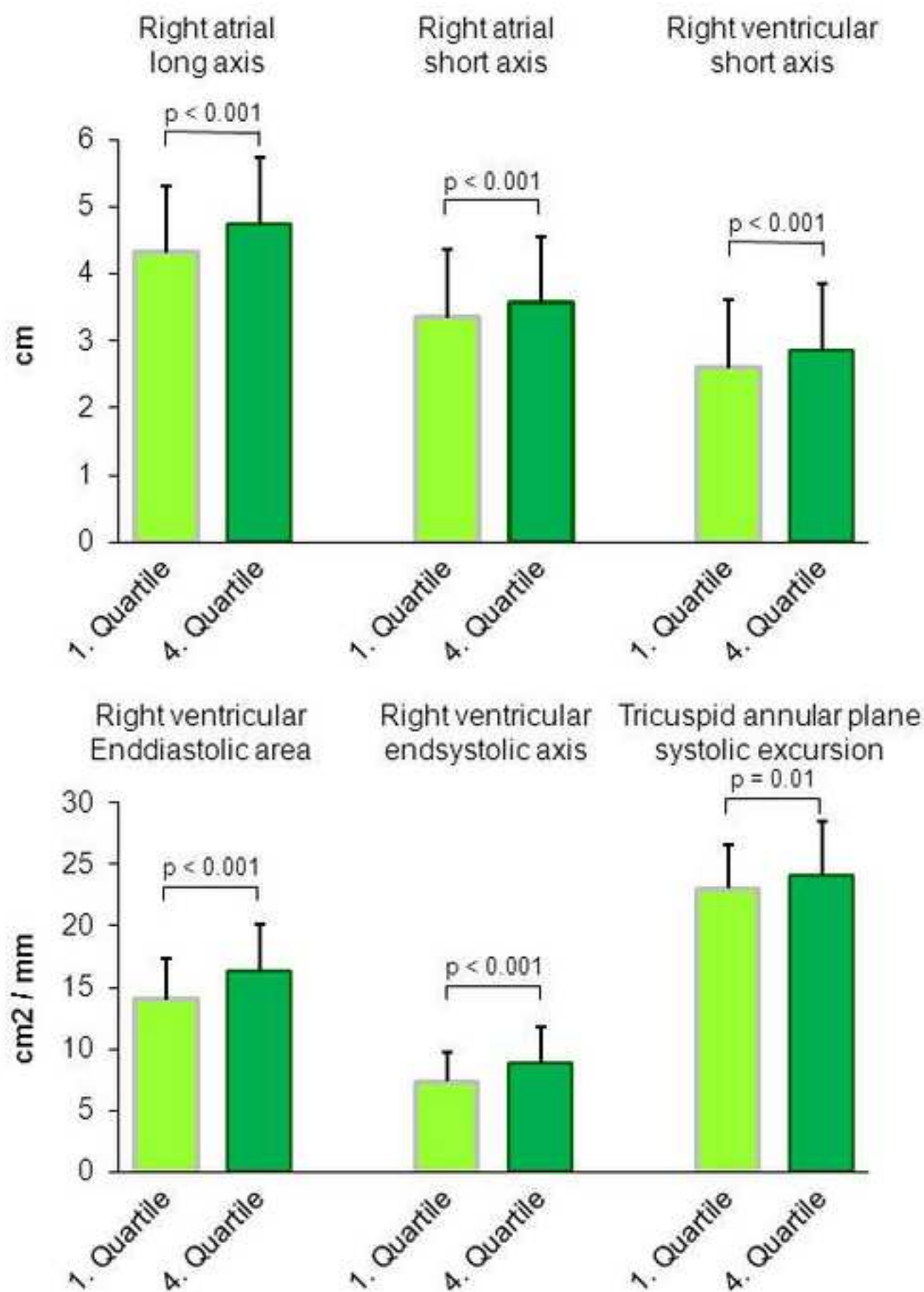


Table 1: Indications for echocardiograms of all 1625 included subjects

Indication	Number of subjects (%)
Suspected heart disease	873 (54)
Cardiac murmur	136 (8)
Rule out structural heart disease	720 (44)
Nonspecific chest discomfort or dyspnoea	228 (14)
Arrhythmia	353 (22)
Systemic Hypertension	139 (9)
Abnormal cardiac appearance on chest radiograph	17 (1)
Healthy individuals	246 (15)
Living organ donor	141 (9)
‘check up’	28 (2)
Screening for familial diseases	77 (5)
Rule out cardiac source of embolism	210 (13)
Assessment prior to potentially cardiotoxic drug treatment	209 (13)
Others	87 (5)

Table 2: Number of subjects in whom individual measurements were available with
corresponding biometric data for each group

Parameter	Number of subjects (n)	Male gender (%)	Average age (years)	Average height (cm)	Average weight (kg)	Average body surface area (m ²)
Right atrial long axis	1496	47%	43 ± 14	171 ± 10	72 ± 15	1.84 ± 0.22
Right atrial short axis	1473	47%	43 ± 14	171 ± 10	72 ± 15	1.84 ± 0.22
Right ventricular enddiastolic short axis	1235	47%	43 ± 14	171 ± 10	71 ± 15	1.84 ± 0.22
Right ventricular enddiastolic area	1145	47%	43 ± 14	171 ± 10	71 ± 15	1.83 ± 0.22
Right ventricular endsystolic area	1133	47%	43 ± 14	171 ± 10	71 ± 15	1.83 ± 0.21
Right ventricular fractional area change	1133	47%	43 ± 14	171 ± 10	71 ± 15	1.83 ± 0.21
Tricuspid annular plane systolic excursion	1144	47%	45 ± 15	171 ± 9	73 ± 15	1.86 ± 0.22

Table 3: Correlations between echocardiographic right heart measurements and biometric parameters

	Height	Weight	Body surface area	Body mass index
Echocardiographic parameter	r	r	r	r
Right atrial long axis	0.30*	0.39*	0.42*	0.24*
Right atrial short axis	0.35*	0.30*	0.35*	0.11*
Right ventricular enddiastolic short axis	0.32*	0.32*	0.35*	0.16*
Right ventricular enddiastolic area	0.42*	0.42*	0.47*	0.20*
Right ventricular endsystolic area	0.37*	0.38*	0.42*	0.19*
Right ventricular fractional area change	-.13*	-.16*	-.17*	-.09*
Tricuspid annular plane systolic excursion	0.07#	0.09*	0.09*	0.06

r = Pearson's correlation coefficient, *p < 0.001, #p < 0.05

Table 4: Gender differences when echocardiographic measurements are indexed to body surface area

Echocardiographic parameter indexed to body surface area	Men	Women	p-value	Difference between means (%)
Right atrial long axis (cm/m ²)	2.4 ± 0.3	2.5 ± 0.3	p < 0.0001	6%
Right atrial short axis (cm/m ²)	1.9 ± 0.3	1.9 ± 0.3	p = 0.9	0%
Right ventricular end-diastolic short axis (cm/m ²)	1.5 ± 0.3	1.5 ± 0.3	p = 0.9	0%
Right ventricular enddiastolic area (cm ² /m ²)	8.7 ± 1.8	7.9 ± 1.6	p < 0.0001	10%
Right ventricular endsystolic area (cm ² /m ²)	4.7 ± 1.4	4.0 ± 1.2	p < 0.0001	18%
Tricuspid annular plane systolic excursion (mm/m ²)	12.0 ± 2.3	13.5 ± 2.5	p < 0.0001	13%

Table 5: Reference values for right heart measurement with and without stratifying for gender and for body surface area

	Parameters normalized for body surface area				Parameters not normalized for body surface area				Parameter not normalized for body surface area and not stratified for gender	
	Women		Men		Women		Men		All subjects	
	Mean	reference ranges#	Mean	reference ranges#	Mean	reference ranges	Mean	reference ranges#	Mean	reference ranges#
Right atrial long axis (cm or cm/m ²)	2.5	1.9 – 3.2	2.4	1.8 – 3.0	4.4	3.4 - 5.4	4.7	3.7 - 5.7	4.5	3.4 – 5.6
Right atrial short axis (cm or cm/m ²)	1.9	1.3 – 2.5	1.9	1.3 – 2.5	3.3	2.3 - 4.2	3.7	2.6 - 4.8	3.5	2.4 – 4.6
Right ventricular enddiastolic short axis (cm or cm/m ²)	1.5	0.9 – 2.0	1.5	0.9 – 2.0	2.6	1.6 - 3.5	2.9	1.9 - 4.0	2.7	1.7 - 3.7
Right ventricular enddiastolic area (cm ² or cm ² /m ²)	7.9	4.6 – 11.2	8.7	5.0 – 12.3	13.5	7.5 - 19.6	16.9	9.8 - 24.0	15.1	7.8 – 22.5
Right ventricular endsystolic area (cm ² or cm ² /m ²)	4.0	1.5 – 6.4	4.7	2.0 – 7.4	6.9	2.4 – 11.4	9.2	3.8 – 14.6	8.0	2.2 – 13.4
Right ventricular fractional area change (%) *	50	30 - 69	46	27 - 65	50	30 - 69	46	27 - 65	48	29 - 67
Tricuspid annular plane systolic excursion (mm or mm/m ²)	13.5	8.6 – 18.5	12.0	7.4 – 16.5	23.4	15.3 – 31.8	23.5	15.9 – 31.0	23.5	15.5 – 31.5

*right ventricular fractional area change is the ratio between 2 absolute measurements; we do not propose to normalize this measurement for body surface area.

reference ranges: Mean \pm 2 SD ¹¹

Copyright Transfer Letter

The undersigned authors transfer all copyright ownership of the manuscript '**Right Heart Assessment by Echocardiography: Gender and Body Size Matters**' to the American Society of Echocardiography, in the event the work is published. The undersigned warrant that the article is original, does not infringe upon any copyright or other proprietary right of any third party, is not under consideration by another journal, and has not been previously published.

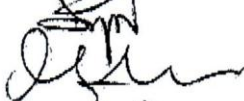
Umberto D'Oronzio



Oliver Senn



Patric Biaggi



Rolf Jenni



Felix C. Tanner



Matthias Greutmann